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Liquid cooled plate heat exchanger for battery cooling of an electric vehicle (EV)

M M Rahman[1], **H Y Rahman, T M I Mahlia, J L Y Sheng**
Department of Mechanical Engineering, College of Engineering,
Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia

E-mail: mujibur@uniten.edu.my

Abstract. A liquid cooled plate heat exchanger was designed to improve the battery life of an electric vehicle which suffers from premature aging or degradation due to the heat generation during discharging and charging period. Computational fluid dynamics (CFD) was used as a tool to analyse the temperature distribution when a constant surface heat flux was set at the bottom surface of the battery. Several initial and boundary conditions were set based on the past studies on the plate heat exchanger in the simulation software. The design of the plate heat exchanger was based on the Nissan Leaf battery pack to analyse the temperature patterns. Water at different mass flow rates was used as heat transfer fluid. The analysis revealed the designed plate heat exchanger could maintain the surface temperature within the range of 20 to 40ºC which is within the safe operating temperature of the battery.

1. Introduction

Recently, there has been a growing demand in newer, cleaner and greener technology where it aims to replace the conventional fossil fuel as primary energy source. The automotive industries are the major innovators in developing new technologies for greener and cleaner vehicles as engineers race to provide their solutions in discovering new energy source in powering the automotive industries. Electric vehicle (EV) has become one of the fast growing innovations in the automotive industries. Auto makers have gone into developing the electric vehicle technology. Vehicles which do not pollute the environment show a very promising sign for the future development in the automotive industries. However, the electric vehicle is still at a juvenile stage where several models that were manufactured mainly for experimental purposes and market research. Auto makers continue to improve their respective models to be made into the mass market for consumers.

The electric vehicle (EV) that is sold in Malaysian market namely the Nissan Leaf uses passive air-cooling as its battery thermal management system (BTMS) which means when the battery is charging, it would not be cooled as the cooling relies on the movement of the car. Hence, the electric vehicle suffers from the loss of driving range and having to replace the battery pack after a short period of time as the heat is not removed from the battery pack compartment. Moreover, in hot climate like Malaysia, the requirement for an active cooling system for the batteries is even greater as the heat could not be transferred out as easily as compared to colder countries. Hence, a battery thermal management system (BTMS) has to be designed for the Nissan Leaf for better adaptation for the hot countries like Malaysia.

[1] Corresponding author: Prof. Dr. Md. Mujibur Rahman.

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There are a few studies that were done on the battery thermal management system [1-3] which shown that having a liquid cooling system in the battery pack possess a few advantageous over forced air cooling. Figure 1 shows the setup of the liquid cooled plate heat exchanger assembled together with the battery pack. As the battery pack is very congested, the total height of the liquid cooled plate heat exchanger is at 5 mm.

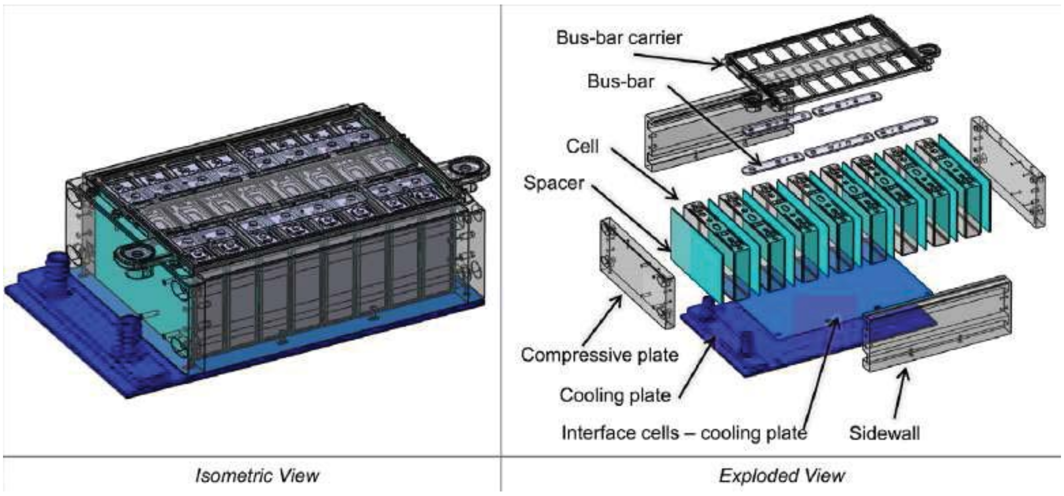

Figure 1 Placement of the liquid cooled plate heat exchanger [3]

Another study on thermal behaviour of the flow channel of the liquid cooled plate is done by Jarrett and Kim [4] in where they studied the optimum design of the electric vehicle cooling plates. They have considered three factors which determine the optimum operating conditions, i.e., pressure drop, average temperature, and temperature deviation where it is subject to a constant heat flux of 500 W/m^2. Another research [5] showed that the mass flow rate of the coolant plays an important role in temperature uniformity and the average temperature. By increasing the mass flow rate, the surface of the plate will eventually reach temperature uniformity where temperature deviation across the surface is close to zero.

2. Methodology

The electric vehicle used as the reference for this design is the Nissan Leaf since it employs a passive air cooling system which relies on the movement of the vehicle to cool the battery. The battery does not have a forced air or liquid cooling when it is charging in its stationary state. The battery used specifically for this case study is same as used in the Nissan Leaf which is is a prismatic cell made from its own manufacturer in Japan.

From the data that is obtained from Nissan, the prismatic battery cell that is used provides a power output of 24 kilowatt per hour and the voltage output of 403.2 volts gives the battery pack to run the 80 kilowatt AC synchronous electric motor a driving range of 84 miles which is roughly 140 kilometers in one single charge. The battery pack contains a total of 48 modules and each module contains 4 prismatic cells equaling a total of 192 cells in the whole battery compartment. The dimensions of the battery pack are listed on the table 1.

Table 1 The dimensions of the prismatic cell, modules and pack of the Nissan Leaf

	Quantity	Length (mm)	Width (mm)	Thickness (mm)
Battery pack	1	1570.5	1188.0	264.9
Battery module	48	303.0	223.0	35.0
Battery cell	192	290.0	216.0	7.1

The battery pack of the Nissan Leaf is placed below the passengers and driver. As according to the manufacturer, the placement of the battery pack at the center of the vehicle will lower the center of gravity for the car as to ensure stability of the car. The battery modules are arranged in such manner where 24 modules are placed vertically and the remaining 24 batteries lie among each other on two sides of the battery pack. Due to the volumetric constraints of a conventional battery pack, ensuring that the terminals of the battery module are not disrupted when the plate is installed is vital to avoid incomplete contact at the terminals which may results in power loss or current leakage. Hence, the height of the liquid cooled plate heat exchanger has to be small [3]. The height of the plate in total will be 5 mm with the radius of the inlet to be set at 2 mm. and the height of the plates to be at 0.5 mm. As the width is much bigger than the height of the plate, it can be assumed that the conduction takes place only in one direction which is the normal to the surface plate.

2.1 Computational Fluid Dynamics (CFD) Model Generation
Figure 2 shows the top view of the flow channel of the liquid cooled plate exchanger.

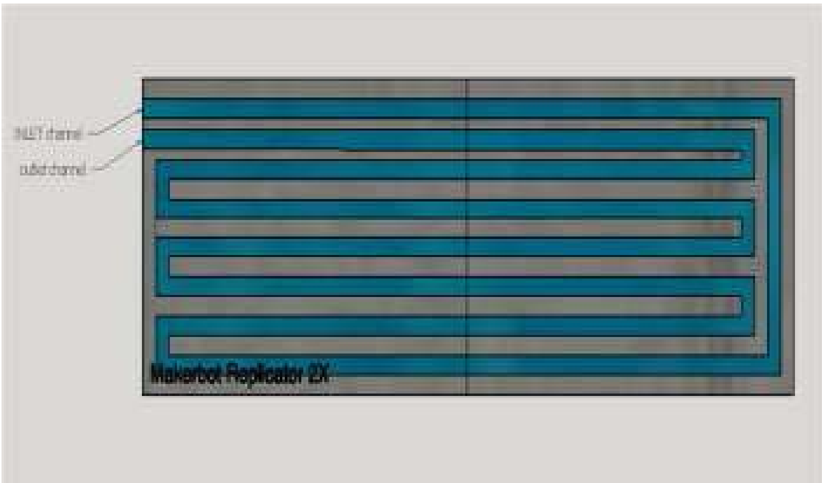

Figure 2 Top view of the single channel design of the liquid plate heat exchanger

The pre-processor, i.e., GAMBIT was used to model the desired geometry before it was exported into the CFD software. Moreover, it is used to mesh the entire surface of the geometry so that the geometry can be plotted out in the CFD software. After the geometry of the plate is modeled out, the meshing is then done on the plate model. A 2-dimensional approach to the liquid plate heat exchanger was done as the thickness of the plate was only 5 mm. Furthermore, since the length of the plate is longer than the thickness of the plate which is 840 mm and 5 mm, respectively, the ends and side thermal effects are negligible. Hence, the thermal analysis from the computational fluid dynamics simulation can be done accurately with two dimension. The use of 2 dimensional simulation can also reduce the computer resources allowing a quicker convergence of the residuals when simulation is done. Once the meshes are generated, the cooling plate is then exported into FLUENT. A uniform heat flux of 500 W/m^2 on the surface of the cooling plate was applied which follow the studies reported in [4]. The coolant flow rates were varied from 0.01 kg/s to 0.05 kg/s. The pressure at the outlet channel was set as zero.

3. Results and discussion
Contour curve of typical temperature distribution at a mass flow rate of 0.03 kg/s is presented in Figure 3 and the outlet temperatures of the water at different mass flow rates are presented in Figure 4.

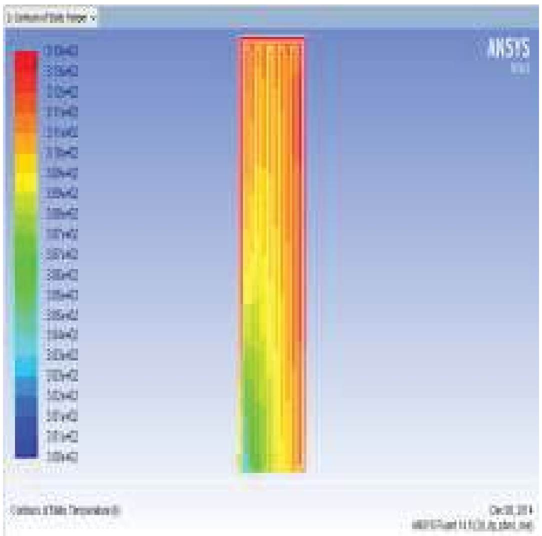

Figure 3 Temperature contour at a mass flow rate 0.03 kg/s

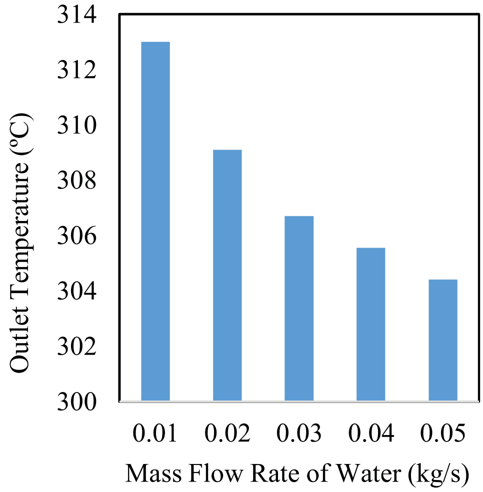

Figure 4 Outlet temperature of water at different mass flow rates

It is clear from Figures 3 and 4 that as the mass flow rate of the cooling fluid increases, the outlet temperature also decreases. As the water flows into the channel duct, heat is exchanged from the top surface of the plate into the duct walls. As the water flows along the channel, heat is transferred due to the temperature difference. Higher mass flow rate decreases the water outlet temperature since water was in contact with the duct surface for a short time hence less hat is swept away by the water.

4. Conclusions

A liquid cool plate heat exchanger was designed to remove excessive heat generated by the battery pack during the operation of an electric vehicle in Malaysian environment. Water was considered as working fluid. The heat transfer analysis was conducted by simulating the flow of water through the heat exchanger by CFD. It was observed that a mass flow rate of water about 0.02 kg/s could remove the excessive heat generated which could maintain the temperature in an allowable level.

5. Acknowledgement

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